Lesquerella fendleri response to different sowing dates in northern Mexico

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Abstract

Lesquerella fendleri (Gray) Wats. is a Brassicaceae native to northern Mexico and southern United States. The seeds contain an oil similar to castor oil that may be used for a wide array of industrial products. The U.S. imports 41,000 t of castor oil per year. Thus, *Lesquerella* oil may be an economic replacement for castor oil. The Mexican growers in the semiarid lands have the potential for cultivating *Lesquerella* if the crop can be grown in the native regions. The object of this study is to determine the effect of sowing date on seed yield and oil content in *Lesquerella* grown at Saltillo located in northern Mexico. The plants were sown at three different dates (23 October 2003, 16 December 2003, and 17 March 2004) and harvested in 2004 on 15 May, 24 June, and 27 August, respectively. Irrigation was applied for germination and seedling establishment and to maintain soil moisture. The experimental design was a complete randomized block design with eight replications. Plant morphological variables as well as yield characteristics were measured and related to sowing dates and climatic conditions. The longer period for crop development was due to shorter photoperiod. Plant densities were highest when the crop was sown in December and March, although the densities of three sown dates were within the reported limit for high yield. Seed yield was highest when the crop was sown in December and the oil content increased in the March planting when the mean temperature during seed formation was highest. Infrared spectra of the seeds crude extracts showed different functional groups that varied with climatic conditions.
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Keywords: *Lesquerella fendleri*; Sowing dates; Seed yield; Oil content

1. Introduction

Lesquerella fendleri (Gray) Wats. is a member of the plant family *Brassicaceae* and native to northern Mexico and southern United States. It produces a seed oil con-

taining a hydroxy fatty acid (lesquerolic acid). Presently, the hydroxy fatty acids (HFA) are industrially used in the manufacture of nylon, lithium greases, sulfonated oils, food grade lubricants, and cosmetics (Kleiman, 1990; Roetheli et al., 1991; Dierig et al., 1993). The current source of HFA is ricinoleic acid from the castor plant (*Ricinus communis* L.). The annual import of HFA in U.S. was 41,000 t of castor oil from Brazil and India at a cost exceeding US$ 100 million/year. The oil from *Lesquerella* may be used for applications

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similar to those of castor oil that is a strategic product for the U.S. (International Flora Technologies Ltd., 1996).

Agronomic management practices for *Lesquerella* include planting method, time of harvest, planting density, fertilization, and irrigation scheduling. Thompson et al. (1989) and Brahim et al. (1996) reported that plant population of 750,000–1,100,000 plants ha^{-1} gave the better yields. *Lesquerella* must be harvested when at least 90% of the seed is mature (243 days after sowing, DAS) until all seeds are mature (264 DAS). In these stages, seed yield, oil content, and lesquerolic acid are maximum and plant density did not affect these variables (Brahim et al., 1996). Dierig et al. (1993) reported that *Lesquerella* is better adapted as a winter crop in Arizona and as a summer crop in cooler Oregon.

Even though *Lesquerella* is native to the semiarid regions, water application (600 mm) improved yield in Arizona. The irrigation quantity is similar to winter wheat in that region (Dierig et al., 1993). The best timing for irrigation was determined by Hunsaker et al. (1998) who reported biweekly irrigation after flowering. Two supplemental irrigations applied in early winter gave the highest dry matter (7020 kg ha^{-1}) and seed (888 kg ha^{-1}) yields. This seed yield was 14, 18, and 20% higher than that obtained by withholding irrigation during midflower, seed formation, and ripening. This practice did not affect seed weight, oil and lesquerolic acid content. Irrigation application at 50% soil water depletion resulted in the highest seed yield to 1125 kg ha^{-1} (Hunsaker and Alexander, 1996). *Lesquerella* grown on desert soils is strongly influenced by N fertilization and split applications (Nelson et al., 1999). The fertilizer rate of 150 kg N ha^{-1} in three applications produced high seed yield (1990 kg ha^{-1}), but did not affect the seed weight or lesquerolic acid content. *Lesquerella* may be classified as a salt tolerant crop with a 19% reduction in seed yield for each unit increase in soil salinity above a threshold of 6.1 dS m^{-1} (Grieve et al., 1997). *Lesquerella* can accumulate selenium, hence there is the potential of its use as a phytoremediator of selenium-contaminated soils and water (Grieve et al., 2001).

Because of commercialization problems for products from traditional agronomic crops in Mexico, the possibility of developing alternative crops such as *Lesquerella* may help farmers in the semiarid northern Mexico.

The objectives of the present research were to study the response of *L. fendleri* to three sowing dates in southeast Coahuila, northern Mexico and to determine the best conditions for high seed and oil yields.

2. Materials and methods

The *L. fendleri* (Gray) Wats. sowing dates study was conducted during 2003–2004 at the Universidad Autonoma Agraria Antonio Narro, Buenavista, Coahuila (25°23′ north latitude and 101°00′ west longitude, 1743 m asl). The soil is clay loam with a water holding capacity of 16 cm m^{-1}, and electrical conductivity of saturated soil extract of 1.2 dS m^{-1}, which is classified as low salinity soil (Richards, 1954). Field preparation prior to each planting included plowing, harrowing, land leveling, and incorporating ammonium sulfate at 80 kg N ha^{-1} and phosphorus pentoxide at 40 kg ha^{-1}. After field preparation, eight experimental plots (4 m × 6 m) were set up with rows 0.33 m apart. *L. fendleri*, line O1LO, was obtained from Dr. David Dierig, U.S. Arid Land Agricultural Research Center and was hand-sown at 8 kg ha^{-1}.

The sowing dates were on 23 October (T1), 16 December 2003 (T2), and 17 March 2004 (T3). After the seeding, sprinkler irrigation was applied for germination and seedling establishment for 1 h every other day for two weeks at a rate of 6 mm h^{-1}. Electrical conductivity of water irrigation was 0.616 dS m^{-1} and represents a medium salinity with low sodium water (Richards, 1954). Because *Lesquerella* is salt tolerant, it can be grown without special practices (Grieve et al., 1997). Total irrigation volumes of 400 mm were applied for T1, 430 mm for T2, and 300 mm for T3. Rainfall was 93 mm (T1), 126 mm (T2), and 248 mm (T3).

The experimental design was a complete randomized block design with eight replications. The sampling area was 5.5 m^2. The plant height and width were measured for the plants in 8 lineal meters up to one week before harvest. The harvests were made when the plants had mature seed pods, on 25 May (T1), 24 June (T2) and 27 August 2004 (T3). The plants were counted within the sampling areas, clipped at the soil line, transported to the laboratory in plastic bags, weighed for fresh matter, air-dried for three weeks, and weighted for dry matter before hand-threshing the seed. The seeds for each planting date were cleaned and weighed. Oil content in duplicate was determined by Soxhlet extraction (18 h) with hexane. For extraction, the seeds were cleaned and milled in a blender, 5 g from this material were wrapped in filter paper (Whatman No. 1), placed in cellulose cartridges (33 mm × 80 mm) for analysis.

The infrared spectra of the ethanol extracts from the seeds were obtained. The extracts were dissolved in dry chloroform and a thin film cast from the solution onto potassium bromide crystals. These were analyzed with a

Table 1

Climatic data for the *Lesquerella fendleri* experiments 2003–2004 in Saltillo, Mexico, day mean value for the month

	2003			2004							
	October[a]	November	December	January	February	March	April	May	June	July	August
Mean temp. (°C)	15.8	15.5	11.4	11.0	12.2	15.9	17.5	20.8	20.7	20.7	19.9
T EV (mm)	69.6	89.2	94.7	77.4	118.2	132.7	163.5	205.8	147.1	157.4	129.1
T RF (mm)	55.7	6.1	2.3	12.5	3.7	12.7	8.7	8.7	78	80.6	60.2
Mean solar rad. (MJ m^{-2} day^{-1})	13.7	12.6	12.4	9.7	13.6	14.8	17.7	18.6	14.5	16.2	13.8
Photoperiod (h:min)	7:47	8:43	7:50	5:44	8:08	8:00	9:44	11:19	7:44	8:43	7:56

[a] Monthly data; temp., temperature; T EV, total evaporation; TRF, total rainfall; rad., radiation.

Table 2

ANOVA mean squares for three sowing dates of *Lesquerella fendleri*

sv[a]	d.f.[a]	Plant density	Fresh matter yield (kg ha^{-1})	Dry matter yield (kg ha^{-1})	Seed yield (kg ha^{-1})	Oil content (%)	d.f.[a]	Plant width (cm)	Plant height (cm)
Repetition	7	2.75×10^{11}	13956086.2**	1317748.3**	70459.1**	0.83	7	21.76	13.70
Sowing	2	3.60×10^{11} **	20263343.5**	5051756.5**	353317.9**	28.35**	1	0.818 NS[a]	215.95**
Error	14	3.36×10^{10}	1623306.4	243779.7	22342.6	1.61	7	2.33	13.97
Mean		9.24×10^{5}	10224.5	5915.4	873.4	25.04		32.80	30.33
C.V. (%)		19.84	12.43	8.34	17.11	5.07		4.65	12.32
DMS		2.73×10^{5}	1366.3	529.5	160.3	1.63			4.42

[a] sv, Source of variation; d.f., degrees of freedom.

** Significant at 0.01 probability level.

Nicolet NEXUS 470 FTIR (Nicolete, WI) using a 4 cm^{-1} resolution acquiring 32 scans per spectrum.

Climatic data for the experiment (Table 1) were obtained from the meteorological station of the University, located at 250 m from the experiment. Data analysis was performed statistically using the SAS release Version 6.12 (SAS Institute Inc., 1996)

3. Results and discussion

The mean air temperatures during the crop cycle development for T1 (15 °C) and T2 (15.6 °C) sowing dates were lower than that for the T3 (19.2 °C). Rainfall was scarce for T1 and T2, whereas for T3, it was very low during the first one-half of the crop cycle and increased for the second half (Table 1). Climatic conditions affected the developmental cycles of the crops. The time required for harvest was 215 days for T1, 191 days for T2, and 153 days for T3. Squire (1993) mentioned that photoperiod affects the time between sowing and the start of reproductive development of the crop, but the later stages are not sensitive to photoperiod. This factor is one of those that influenced the differences between the cycle duration. The crop had the longest developing cycle in the T1 (October) sowing date and shortest photoperiod (Table 1). In contrast, in the T3 (March) sowing date had the shortest developing cycle and longest photoperiod.

The ANOVA mean squares for the evaluated characteristics of *L. fendleri* are listed in Table 2. Significant differences ($P \leq 0.01$) were present for the sowing dates, except for plant width.

Table 3

Mean comparison of several characteristics for *Lesquerella fendleri* evaluated at different sowing dates

Sowing date	Plant density	Fresh matter yield (kg ha^{-1})	Dry matter yield (kg ha^{-1})	Seed yield (kg ha^{-1})	Oil content (%)	Plant width (cm)	Plant height (cm)
October	724009 b[a]	8782.6 b	5284.6 b	824.5 b	23.1 c	33.1	26.7 b
December	1146733 a	11939.7 a	6807.9 a	1103.5 a	25.2 b	32.6	34.0 a
March	903314 ab	10010.2 b	5653.7 b	691.7 b	26.8 a	ND	ND

ND, not determined.

[a] Means followed by different letters in a column are significantly different at the 0.05 level.

Plant density obtained at harvest (Table 3) for T2 of 1,146,733 plants ha^{-1} was statistically equal ($P \leq 0.01$) to that of T3 date (903,314 plants ha^{-1}) and higher than T1 (724,009 plants ha^{-1}). Differences in the number of plants are attributed to germination problems caused by seed dormancy and emergence. According to International Flora Technologies Ltd. (1996), the establishment problems of *Lesquerella* are due to lack of moisture control that leads to seed dehydration, soil crusting, as well as light requirements for germination. For our experiments, the soil surface was maintained moist with frequent irrigation. However, light and air temperature were lower for the T2 (December) sowing date. These may be the factors responsible for higher plant germination and higher plant density. The reported optimum plant density is between 750,000 and 1,100,000 plants ha^{-1} (Thompson et al., 1989; Brahim et al., 1998), and our experiments plant densities were within these limits.

Plant height was 34 cm for the second sowing date (Table 3), 21.6% significantly higher ($P \leq 0.01$) than the first sowing date, this is due to a higher plant density in the first date that reduces availability of light and space (Brahim et al., 1998).

The yield of fresh plant matter (Table 3) for T2 was 16.2% significantly higher ($P \leq 0.01$) than T3 and 26.4% higher than the T1. Similar results were presented for the dry matter yield, T2 was 16.9% significantly higher ($P \leq 0.01$) than T3 and 22.3% higher than the T1. Dry matter yield is the result of several environmental factors affecting plant development such as water, soil, solar radiation, and temperature (Fageira, 1992). The seed yield (1103 kg ha^{-1}) for T2 was 25% greater than T1 and 37% greater than T3. The highest seed yield is acceptable value and agrees with the 1125 kg ha^{-1} of Hunsaker and Alexander (1996), but lower than the 1400 kg ha^{-1} of Brahim et al. (1998) and 1990 kg ha^{-1} of Nelson et al. (1999).

In the T3 (March) sowing date, the oil content in the seed was 26.8% higher ($P \leq 0.01$) than the other two dates (Table 3). Oil content in the seed did not vary significantly with plant density (Brahim et al., 1998) or irrigation (Hunsaker et al., 1998). Water and soil electrical conductivity values lower than 1.4 dS m^{-1} did not affect the oil content (Grieve et al., 1997). In sunflower, the major fatty acids are oleic acid and linoleic acid, and related to the duration of high temperatures during the seed growth. Fatty acid composition of the oil determines its use as industrial or edible oil (Osorio et al., 1995). We found that the oil content in *L. fendleri* was affected by temperature during seed formation (Fig. 1). This result agrees with Brahim et al. (1998) who reported that high temperature increased oil content in the seed.
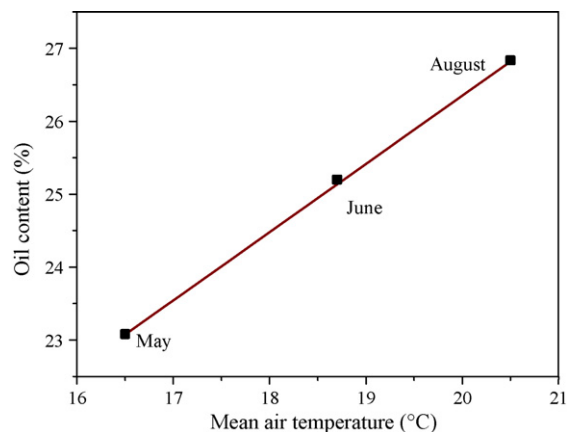

Fig. 1. *Lesquerella fendleri* seed oil content as a function of mean air temperature during grain filling for the three sowing dates, May (T1), June (T2), and August (T3).

Infrared analysis of the ethanolic extracts of the seeds showed several bands corresponding to hydrocarbons and functional groups. The spectra for extracts for the three harvests are shown in Fig. 2. The absorbance of relevant signals was measured to compare the signal intensities of the different treatment samples. The following ratio was calculated:

$$\frac{A_{signal}}{A_{2854}}$$

That is, the C, H signal was used as a reference. The results are presented in Table 4.

Although the unrefined extracts are a complex mixture of chemicals, detection and identification of the following functional groups was possible: hydroxyl (OH) at 3453 cm^{-1}, possibly aromatic at 3006 cm^{-1}, carboxyl (COO, C=O, HC=O) at 1740–1666 cm^{-1}, and long sequences (chains) of CH$_2$ groups at 722 cm^{-1}.
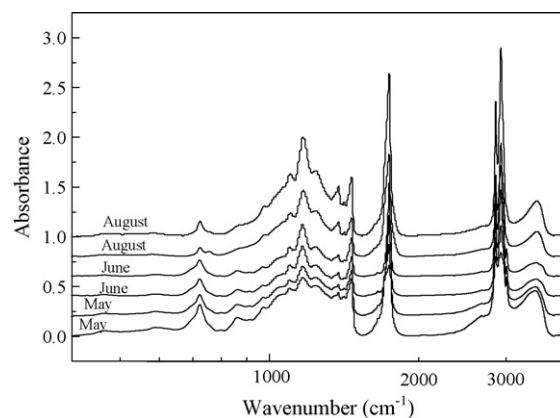

Fig. 2. Infrared spectra of ethanol extracts of *Lesquerella fendleri* seeds from the three harvest dates.

Table 4
Absorbance ratios for different wavelength signals of the ethanol extracts of *Lesquerella fendleri* seeds harvested at different dates, using the $2854\,cm^{-1}$ signal as a reference

| Harvest date (sowing date)	Wavelength (cm^{-1})								
	3453	3008	2854	1746	1666	1462	1377	1170	723
25 May (first sowing date)	0.363	0.4931	1.0	0.9178	0.1232	0.5821	0.4041	0.6369	0.2671
24 June (second sowing date)	0.1911	0.3529	1.00	0.9632	0.0551	0.4595	0.2794	0.5955	0.2022
24 June (second sowing date)	0.1351	0.2905	1.00	0.9932	0.0405	0.4054	0.2263	0.5472	0.1722
27 August (third sowing date)	0.3054	0.2552	1.00	1.2677	0.1004	0.4686	0.4309	0.8117	0.1087
27 August (third sowing date)	0.2601	0.2276	1.00	1.2073	0.0772	0.439	0.3658	0.7317	0.1097
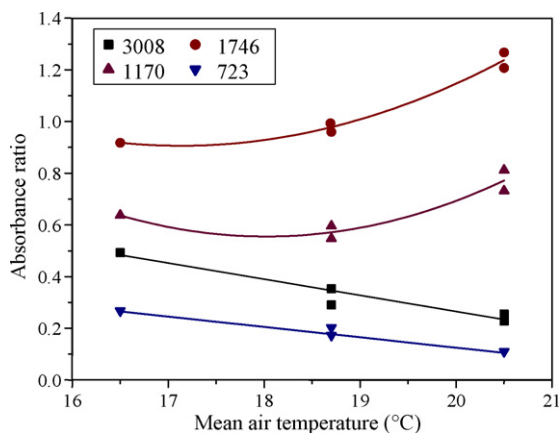
Fig. 3. Infrared signal ratios for the ethanol extracts of *Lesquerella fendleri* seeds from the three harvest dates as a function of mean air temperature.

Structural determinations were not made in this study. The variation of all signals in Table 4 was analyzed as a function of the mean temperature for the three sowing dates. Some signals did not change or the trend was not clearly defined, but those that showed clear tendencies are presented in Fig. 3. The bands at 3008 and $723\,cm^{-1}$ decreased as temperature increased, whereas the signals at 1746 (carboxyl) and $1170\,cm^{-1}$ (aromatic, esters or alcohols) increased. The carboxyl signal may be associated with oil content increments although other compounds must be present because oil content was a lineal function of temperature as seen in Fig. 2.

4. Conclusions

The plant density, plant height, fresh and dry matter, and seed yield were higher for the December sowing date than with the October or March sowing dates. Thus, the best sowing date determined for this environmental condition is mid-December. The crop development cycle span was an inverse function of the photoperiods duration. Plant density in the experiments depended on

sowing date, but was within the reported limit for high yield.

Higher temperatures during the period from seed filling stage to harvest increased oil content in the seed.

Fresh and dry matter yields, seed yield, and oil content obtained for the second sowing date of 16 December sowing date may be considered acceptable and possibly may be improved by proper agronomic management, including fertilization, irrigation scheduling, and plant density. However, more information is needed for determining plant emergence and germination.

The changes in the infrared spectra showed a relation of the functional groups with temperature. Additional analyses of compounds present in the oil are required to identify the compounds responsible for the changes.

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